Climate Change Fuel Cell Program

Project Title

Premium Energy for Companhia Paranaense de Energía Copel Data Center Curitiba, State of Parana. Brazil

Final Report

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Abstract:

In August 2001 a 200KW Phosphoric Acid Fuel Cell (PAFC) Power Plant. was installed at Companhia Paranaense de Energia (COPEL) Data Center
The power plant installed at Copel site is the first of its kind in the Southern Hemisphere. Its presence, marked the point of entry as a reference for the creation of a Fuel Cell Stationary Power market not only for Brazil but also for the rest of the region.
On its first year the power plant has operated 8,403 hours achieving an availability factor of 94% and supplying 1,156MWh of premium energy.
As a first regional experience with fuel cell technology, we expect this report about Copel PACFC power plant performance and cost-benefit evaluation will provide relevant information for future regional investments on this technology.

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Executive Summary

On August 2001, a 200kW PAFC power plant was installed at Companhia Paranaense de Energia "COPEL", the first of its kind in the Southern Hemisphere.
Its presence, marked the point of entry as a reference for the creation of a Fuel Cell Stationary Power market for the rest of Brazil and the rest of the region.
For this reason a flagship entity like Copel admired and respected throughout the world a leader in electrical generation, transmission and distribution was chosen as a key central project for them to continue to develop alternatives to protect the environment and create the investment climate for non polluting technologies.
The power plant application consists on supplying premium power to Copel´s Data Center responsible for billing 2.7 million customers. The data center operates 24 hours a day, 365 days per year and power plant was acquired to be the main electrical source for the building.
During this period the power plant operated 8,403 hours reaching an availability factor of 93.68%. The resulting availability factor achieved the expectations and was in accordance to manufacturer records and former experiences recorded by DoD for the same power plant model.
Nine shutdowns were registered, two of them were scheduled outages and seven were forced outages. Regarding the forced outages, one was due to human error, one was a consequence of an external device malfunction and two were the result of electrical maneuvers performed by Copel personnel. The remaining three forced outages had straight relationship with the power plant performance and were due to problems detected with the variable speed drive associated to the power plant water pump and the inlet fuel valve. Resulting in a MTBFO of 1,200 hours was not the desirable outcome expected that must be improved in the future.
To generate 1,156MWhrs the power plant consumed 298,061 m3 (10,525,926.7 cf) of natural gas reaching an electrical efficiency of 39% at gas LHV and 35% at gas HHV. Results were not only consistent with the recorded experiences with same units, but demonstrates the power plant higher efficiency compared with average results for gas turbines and diesel generators that can reach up to 30%.
The power plant thermal output was utilized to supply domestic hot water to a restaurant located adjacent to the Copel Data Center. Thermal load demand involved the heating of 5,000litres per day (1,321 gallons) from 20ºC (68ºF) to 72ºC (162ºF). This represents a heat recovery rate of 43,054Btu/h and a resulting thermal efficiency of 3.54% at natural gas LHV and 3.26% at natural gas HHV.
As expected no harmful emissions of NOx, SOx were detected, demonstrating the fact that fuel cell technology contributes to the overall benefit of the environment.
In terms of the cost benefit analysis the power plant is still an expensive alternative when compared with traditional power generation. According to the project demands the resulting cost for kWh generated, including amortization and maintenance costs, was USD 0.16967 (natural gas HHV), versus to USD 0.04544kWh conventional rate for 13.8kV medium voltage, USD 0.07645kWh residential low voltage rate and USD 0.07149kWh commercial and industrial low voltage rate. The main factors that affect results are application demand (electrical and thermal demand); increase of maintenance cost as a result of the forced outages; the high cost of natural gas compared with conventional electric rates and finally the power plant acquisition cost.
The main project conclusion is that fuel cell technology demonstrated to be a reliable option for the vision of distributed power generation as an important alternative for non-polluting power generation.
The achievement of this project contributed to the regional evaluation of fuel cell technology, providing technical and commercial know how that will be applicable and very valuable when considering further regional projects.

Introduction

The Global demand for power has created a large need to develop alternative sources of energy that will become pollution free energy sources. In the case of South America and specifically Brazil, climate changes have seriously affected the environment and the supply of power to meet the growing demand. As these economies become part of the global mainstream, clean energy alternatives can be addressed by the use of Stationary Power Fuel Cells.

Sieco S.A. (Sieco) became involved with United Technologies Fuel Cell, Inc. (former International Fuel Cells, Inc.) in 1997 and have been promoting and marketing the PC25 Power Plant based on Phosphoric Acid Fuel Cell Technology in the South America region.

From the beginning, Sieco has focused on providing Premium Power Solutions to the region and on March 2001 was able to successfully execute on its efforts by bringing the first three Fuel Cell Power Plants into Brazil, the first in the South American territory.

The installation of the first power plant at Companhia Paranaense de Energia (COPEL) Data Center located in the State of Parana, known as the Green State of Brazil due to its environmental awareness acted as the point of entry of this technology in the region.

During the first operational year, project objectives were focused on the technology evaluation, acquisition of technical and commercial know-how based on the technology strengths and weakness and the economical factor that may bridge distributed generation using fuel cell technology as a viable option.

Project Schedule and Installation

The project implementation began with the purchase of the unit on March 12, 2001. The purchased involved a 200kW Phosphoric Acid Fuel Cell (PAFC) model PC25C manufactured by United Technologies Fuel Cell (former IFC), capable to operate independent of the utility grid. The power plant was required with a low grade heat recovery heat exchanger that it is a standard option for the unit and an optional double walled heat recovery heat exchanger.

The power plant electrical configuration was according to U.S. market standards for that reason it was necessary to procure the addition of two transformers to meet the power plant input / output requirements by the utility grid. Even though it was not required as an additional security measure, a reverse osmosis system to treat water inlet was included.

The unit was placed outdoors, adjacent to the Copel Data Center, it was conceived to operate with natural gas, 24 hours a day, 365 days per year (except for scheduled maintenance) and its main application is to provide Premium Power to the data center that includes the billing operation of Copel's 2.7 million customers.

The technical training at the manufacturer's facility in the USA was conducted on April 2001. Site engineering was concluded on May 2001. The Fuel Cell Power Plant was delivered to the site on June 5, 2001. Permits and site preparation were originally scheduled to be concluded on April, 2001, but the project suffered several deviations because of delays during the construction work conducted by Brazilian gas company Compagas, they were related to piping the natural gas to the site that wasn't available at the power plant location.

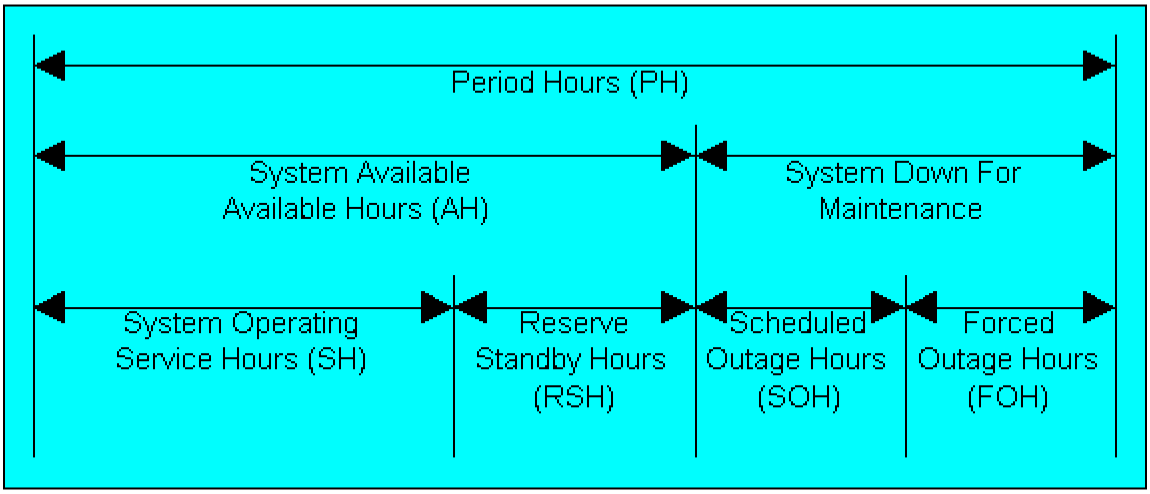
Finally unit installation began on July 2001 and system first start-up took place on August 23rd, 2001 reaching the maximum capacity of 200kW on the same date.

Results and Discussion

Reliability Metrics

The performance indices available at Gas Technology Institute (GTI) in Des Plaines, Illinois (http://www.gri.org/pub/solutions/dg/rel_metrics.html), were selected to measure power plant reliability.

Tables and graphs showing different reliability categories for a given period of time, applied reliability indices, their definitions and results follow:



Data	***Code***	***Result***
Period of Hours **Period Aug 23-01 / Aug 31-02**	PH	8970 Hours
System Available - Available Hours	AH	8403 Hours
System Down for Maintenance	SD	567 Hours
System Operating Service Hours	SH	8403 Hours
Reserve Standby Hours	RSH	0 Hours
Planned Outages	PO	2 Event
Scheduled Outage Hours	SOH	196 Hours
Forced Outage	FO	7 Events
Forced Outage Hours	FOH	371 Hours

Indices:

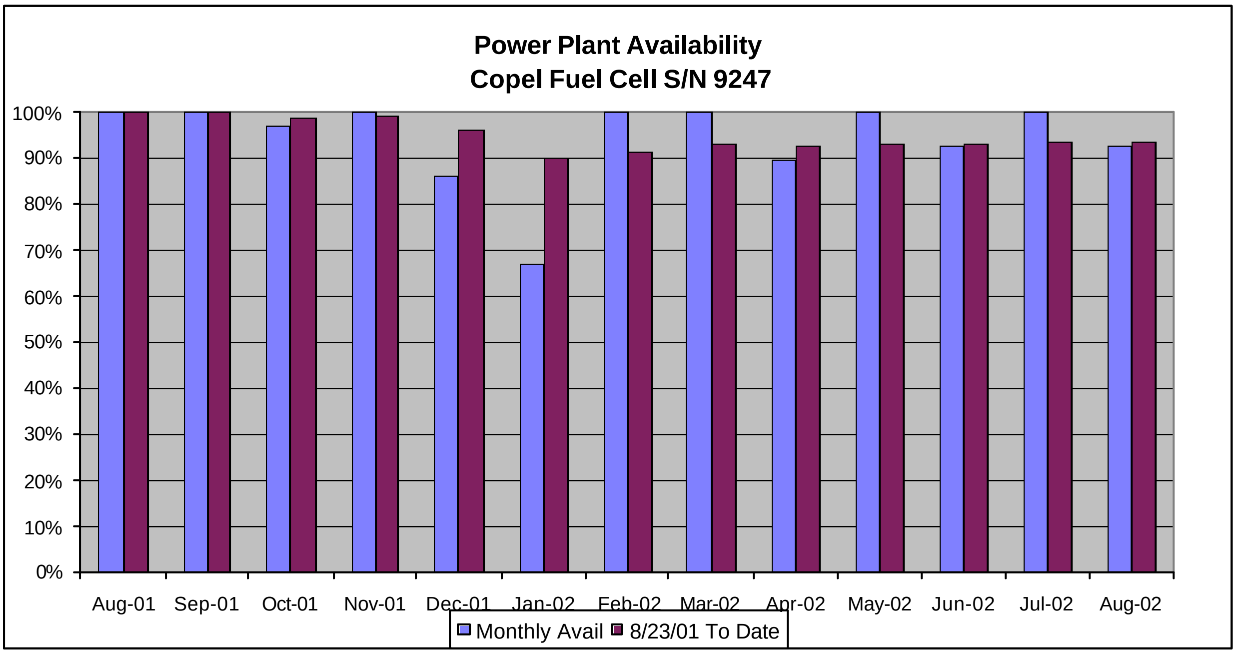
Indices:	Formula	Result
Period of Demand (POD) *Measures the time the unit was planned to operate*	POD = PH - RSH - SOH	8774 Hours
Availability Factor (AF %) *Measures, on a percent basis, the unit's "could run" capability. Impacted by planned and unplanned maintenance*	AF= (PH - SOH - FOH) x 100 / PH	93.68%
Forced Outage Rate (FOR %) *Measures portion of downtime due to unplanned factors*	FOR = FOH x 100 / SH - FOH	4.62%
Scheduled Outage Factor (SOF %) *Measures percent of time set aside for planned maintenance*	SOF = SOH x 100 / PH	2.19%
Service Factor (SF %) *Percent of total period hours the unit is on-line – varies due to site-related or economic factors*	SF = SH x 100 / PH	93.69%
Mean Time Between Forced Outages (MTBFO) *Measures the nominal time between unscheduled forced outages*	MTBFO = SH / FO	1200 Hours
Mean Down Time (MDT) *Measures the nominal duration the unit is down during maintenance events*	MDT = SOH + FOH / FO + PO	63 Hours

Operating Hours / Availability:

Until August 2002, Copel power plant logged 8,403 operating hours, reaching an availability factor of 93.68% during the total period of time demanded (calendar time).

On November 2001 DOD published their experience with a fleet of 30 power plants generators, comparing reported availability rate for the PC25C model (87%), Copel fuel cell availability factor not only achieved the expectations but also proved high system availability.

Availability Chart:



Mean Time Between Forced Outages:

During the analyzed period Copel power plant registered nine shutdowns. Two were a result of scheduled maintenance activities and seven were forced outages. Despite four of the seven forced outages had not a straight relationship with the unit, resulting in a MTBFO of 1200 hours, which was far away from manufacturer 2500 hours records or DOD reported historical experience for the same model of 1766 hours.

The cause for first forced outage was associated with utility grid instability. The system configuration involved that the power plant operates in parallel to the utility grid as the main electrical source for the Data Center, with the commercial utility grid as a back up in case of failure on the unit. During start up it was notice that VSD 830 (variable speed drive associated to fuel cell water pump) Input AC voltage limit (500V) was not large enough to support grid utility voltage variations. It was scheduled a VSD replacement with an Input AC voltage limit of 515V. First forced outage occurred before replacement and was caused when VSD could not support utility voltage disconnecting the power plant.

Second reason for shutdowns associated to power plant performance were related to power plant inlet fuel valve that for an undetermined reason gets blocked. Regardless that on August 19th, the gas pressure was adjusted and verified the gas ejector, the problem still remains and it is under research to look for the solution.

Following there is a chart with a summary of scheduled and forced outages.

Shutdowns Summary:

Event / Description	Date Month/Date/Yr	Load Time	Run Hours	System Down Hours
First Start Up # 9247	8/23/2001 4:25	358		
Shutdown *Inverter shutdown due to problems with VSD830*	10/16/2001 15:34	1665	1307	
Restart	10/17/2001 12:34	1665		21
Shutdown *Field Service Error*	12/6/2001 14:07	2867	1202	
Restart	6-Dec-01 17:58	2867		4
Shutdown *Problems with RO System causing a leakage into unit.*	12/27/2001 14:58	3368	501	
Restart	1/4/2002 12:44	3368		190
Shutdown *Scheduled shutdown to replace VSD 830*	1/4/2002 13:06	3368	0	
Restart	1/11/2002 13:53	3368		169
Shutdown *Inverter shutdown, because a internal fuel inlet valve malfunction*	4/1/2002 10:53	5285	1917	
Restart	4/4/2002 13:10	5285		74
Shutdown *Inverter shutdown, due to overload caused by customer electrical maneuvers*	6/8/2002 8:10	6840	1555	
Restart	6/8/2002 17:42	6840		9
Shutdown *Inverter shutdown, due to overload caused by customer electrical maneuvers*	6/12/2002 11:42	6932	92	
Restart	6/14/2002 10:01	6932		46
Shutdown *Scheduled shutdown to adjust gas preassure and check gas ejector*	8/18/2002 23:01	8505	1573	
Restart	8/20/2002 2:06	8505		27
Shutdown *Problems with natural gas inlet valve*	8/21/2002 13:06	8540	35	
Restart	8/22/2002 16:13	8540		27
Last Measuring	8/31/2002 22:13	8762	222	

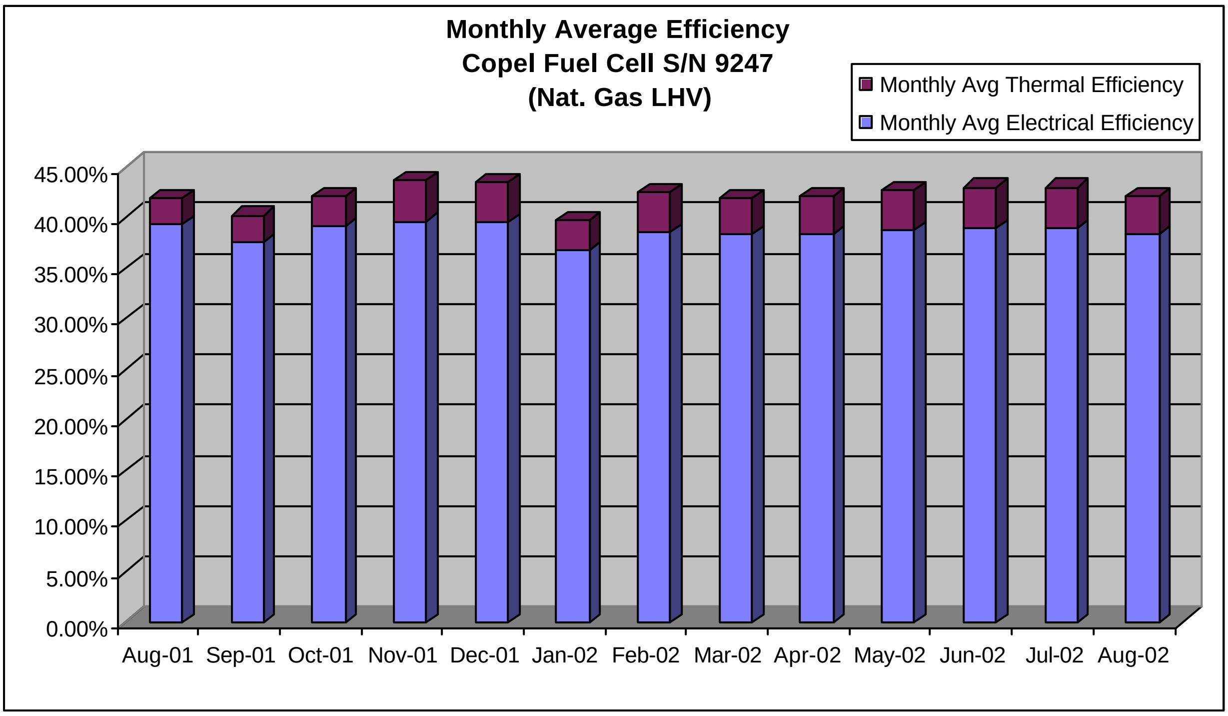
Efficiency

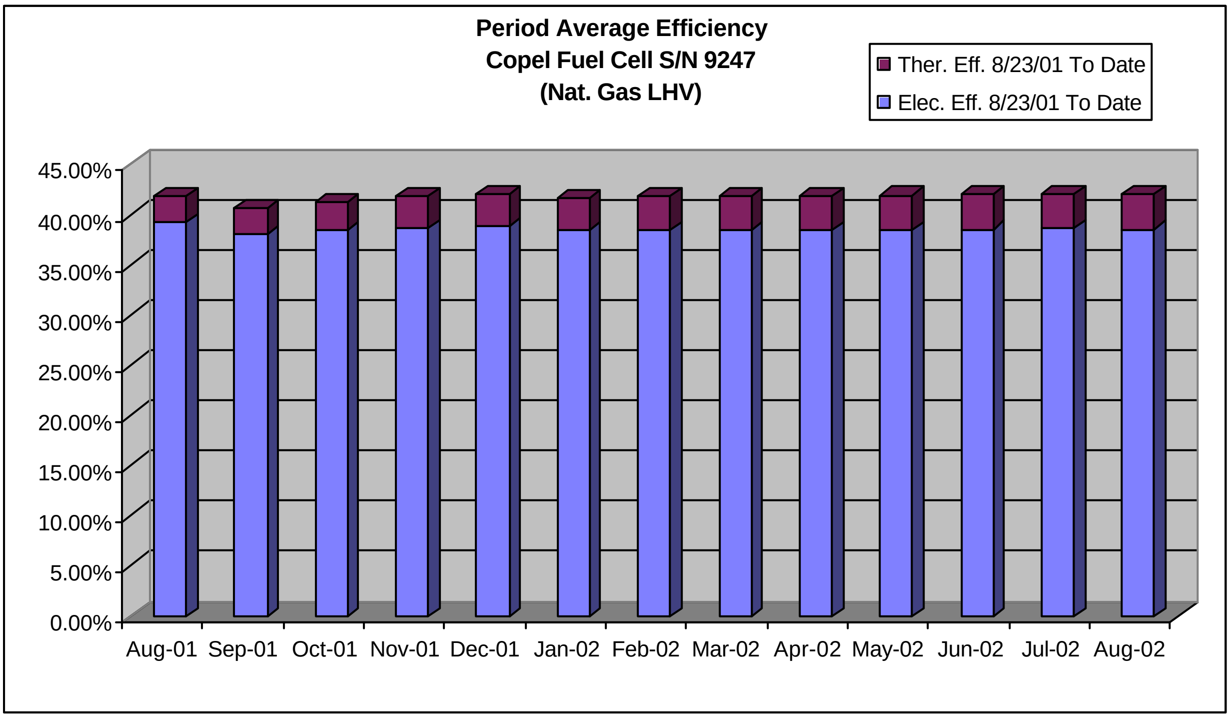
Information published by the natural gas vendor, "Compagas", was included to estimate the system efficiency. Following are the listed Compagas heat value for natural gas and units conversion.

Natural Gas LHV = 8650kcal/m3 = 10,06kWh/m3 = 34326Btu/m3 = 972Btu/cf.
Natural Gas HHV = 9400kcal/m3 = 10,93kWh/m3 = 37292Btu/m3= 1056Btu/cf.

During period Copel power plant operated at an average AC Output of 133Kw (67% of its total capacity) presenting an electrical conversion efficiency at natural gas LHV of 39% with a maximum efficiency record of 40% and a minimum of 37%. At natural gas HHV electrical conversion efficiency dropped to 35% (+/- 1%).
The recorded electrical conversion efficiency almost achieved manufacturer parameters of 40% (LHV) for the power plant beginning of lifetime and it is consistent with DOD recorded experience of 39% +/- 2% (LHV) and 35% +/- 2% (HHV).
Average electrical conversion efficiency for other gas engines like turbines or diesel generators ranges between 25% to 30%. When comparing these figures, it is demonstrated the power plant higher electrical conversion efficiency with the additional benefit that the power plant does not burn consumed fuel therefore, reducing polluting emissions.

Thermal efficiency is considered the ratio between heat recovered versus consumed natural gas heat content. Despite the power plant heat available limitation (750.000 Btu/h – 220Kw/h t at 200kw/h e power rate), thermal efficiency is affected by thermal load demand. Heat not recovered by the thermal load is exhausted by the power plant cooling module, turning it into power plant waste.
Copel power plant thermal load consists of providing domestic hot water to an adjacent restaurant. The restaurant demand is 5000litres per day (1321 gallons per day) of domestic water, heated from 20ºC (68ºF) to 72ºC (162ºF). It represents a heat recovery rate of 43.054Btu/h and a resulting thermal efficiency of 3.54% at natural gas LHV and 3.26% at natural gas HHV.

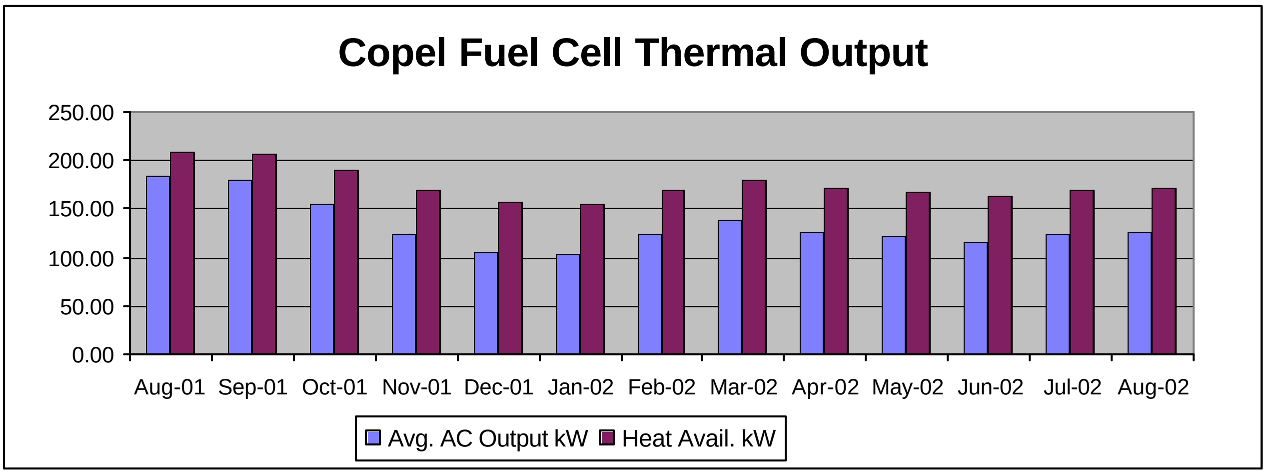




Thermal Output

The thermal output considered as the available heat rate, independent of thermal consumption, has relationship to the power plant AC Output Voltage. At a maximum rated power of 200kW the power plant model PC25C is able to supply 750.000Btu/h (220kW).

According to the manufacturer records from 200kW to 100kW AC Output, available heat rate drops 3% per 5% AC Output reduction. Therefore the following chart shows available heat in kW according to Copel power plant monthly AC output average.



Emissions

The following chart shows Copel Power Plant emissions:

Emissions	Copel Fuel Cell Emissions (ppmv, 15% O2, Dry)
NOx	1ppm
SOx	Negligible
NO2	Negligible
SO2	2ppm
CO	5ppm
Particulates	Negligible
Smoke	None
Hydrocarbons (Not reformed Methane)	6ppm

As expected no harmful emissions were generated, confirming the use of fuel cell technology as a pollution free source of energy.

Cost Benefit Analysis

Currency Exchange:

During the analyzed period the Brazilian currency Real (R$) has suffered a continuos depreciation compared with the USA Dollar (USD). Considering the currency exchange monthly fluctuation (August 2001 USD 1 = R$ 2,51 / August 2002 USD 1 = R$ 3,13) a value of USD 1 = R$ 2,632 was used for the project analysis.

Investment:

The following chart shows investment forecasted at the beginning of the project versus its result at the end of it.

Investment as Planned on March 2001

Item	Description	Cost	Percent
1	Fuel Cell & Miscellaneous	USD 840,000.00	86%
2	Installation Cost	USD 40,000.00	4%
3	First Year Fuel	USD 80,000.00	8%
4	First Year Maintenance	USD 20,000.00	2%
5	**Total Planned Cost**	**USD 980,000.00**	**100%**

	Funding Source	Amount	Percent
6	Sieco S.A.	USD 980,000.00	100%
7	-	-	-
8	**Total Funding**	**USD 980,000.00**	**100%**

Investment as is, on August 2002

Item	Description	Cost	Percent
1	Fuel Cell & Miscellaneous	USD 862,650.00	82%
2	Installation Cost	USD 77,222.92	7%
3	First Year Fuel	USD 82,739.32	8%
4	First Year Maintenance	USD 23,581.90	2%
6	**Total Cost**	**USD 1,046,194.15**	**100%**

	Funding Source	Amount	Percent
7	Sieco S.A.	USD 846,194.15	81%
8	DOE	USD 200,000.00	19%
9	**Total Funding**	**USD 1,046,194.15**	**100%**

Economical Analysis:

To evaluate the project economical results for the period, the capital amortization, power plant maintenance cost and natural gas consumption cost during the period compared to the cost of displaced natural gas and displaced electrical energy obtained from the cogeneration process was considered.

Second the Electrical Energy cost was compared, as a by-product of the power plant cogeneration process, versus available Electrical Energy rates into the State of Parana. The analysis determines the power plant requirements to be considered as a viable generation source.

1-Capital Amortization:

The power plant cost, plus installation cost and an amortization period of ten years was considered.

$$\text{Capital Amortization} = \frac{\text{Power Plant Cost + Installation Cost}}{\text{Amortizing Period}} = \frac{\text{USD 862,650.00 + USD 77,222.92}}{10} = \text{USD 93,987.29}$$

2-First Year Maintenance Cost:

It was equal to USD 23,581.90

3-Cost of Consumed Natural Gas:

Compagas, is the company that supplies of natural gas to Copel power plant. The following is the listed Compagas Rate Chart and the resulting natural gas rate during the period for Copel Power Plant.

Vol. M3 / day	Gas Rate R$	Gas Cost With Discount (10%) R$	Gas Cost With Discount (10%) USD = R$ 2,632 USD
0 to 500	0.871444	0.7842996	0.297986
501 to 1000	0.732222	0.6589998	0.250380
1001 to 2000	0.627555	0.5647995	0.214589
2001 to 4000	0.575333	0.5177997	0.196732

Prices according to COMPAGAS Rates (http://www.compagas.com.br/port/tabelaprecos.asp?tipo=1)

The resulting rate is obtained prorating daily natural gas consumed in m3 per each rate parameter.

Example: Power plant at rated power 200kw consuming 57m3/h of natural gas.

Consume: 57m3/h * 24 = 1.368m3/day

$$\text{Rate} = \frac{\text{(500m3 * USD 0.297986) + (500m3 * USD 0,250380) + (368m3 *USD 0,214589)}}{\text{1,368m3}} = \text{USD 0.258152m3}$$

During this period the Copel Power Plant consumed 10,525,926.7 cubic feet of natural gas, equal to 298,061.09m3 at an average rate of USD 0.277625m3. Resulting on a total cost of USD 82,749.32

Copel Power Plant Consumed Natural Gas Cost Chart:

Fuel Cell Avg. Gas Rate	Fuel Cell Avg. Gas Rate	Fuel Cell Nat. Gas Consume	Fuel Cell Nat. Gas Cost
R$ 0.73071 **m3**	USD 0.277625 **m3**	298,061.09 **m3 (LHV)**	USD 82,749.32
R$ 0.73071 **m3**	USD 0.277625 **m3**	298,061.09 **m3 (HHV)**	USD 82,749.32
R$ 0.02129 **Kbtu/h (LHV)**	USD 0.008088 **Kbtu/h (LHV)**	10,231,200.75 **Kbtu/h (LHV)**	USD 82,749.32
R$ 0.01959 **Kbtu/h (HHV)**	USD 0.007445 **Kbtu/h (HHV)**	11,115,378.60 **Kbtu/h (HHV)**	USD 82,749.32
R$ 0.07264 **kWh (LHV)**	USD 0.027597 **kWh (LHV)**	2,998,469.00 **kWh (LHV)**	USD 82,749.32
R$ 0.06686 **kWh (HHV)**	USD 0.025402 **kWh (HHV)**	3,257,596.00 **kWh (HHV)**	USD 82,749.32

4-Cost of Displaced Natural Gas due to Thermal Utilization:

As discussed on the efficiency section, Copel Power Plant Thermal Heat Recovery rate for the period was 43,056Btu/h and was utilized to supply domestic hot water to an adjacent Restaurant. In order to determine its equivalent cost as displaced natural gas, it is considered gas rate to the Restaurant consumption level, considering gas high and low heat value, and the use of a boiler with 70% efficiency.

$$\text{Natural Gas Rate (LHV)} = \frac{43{,}056\text{Btu/h} * 24\text{hs} / 0.70}{34{,}326\text{Btu/m3 (Nat. Gas LHV)}} = 43.00\text{m3/day} = \text{USD } 0.297951\text{m3}$$

$$\text{Natural Gas Rate (HHV)} = \frac{43{,}056\text{Btu/h} * 24\text{hs} / 0.70}{37{,}292\text{Btu/m3 (Nat. Gas LHV)}} = 39.59\text{m3/day} = \text{USD } 0.297951\text{m3}$$

$$\text{Dis. Nat. Gas Cost (LHV)} = \frac{43{,}056\text{Btu/h} * 8{,}403.38\text{hs} / 0.70}{34{,}326\text{Btu/m3 (Nat. Gas LHV)}} * \text{USD } 0.297951\text{m3} = \text{USD } 4{,}487.09$$

$$\text{Dis. Nat. Gas Cost (LHV)} = \frac{43{,}056\text{Btu/h} * 8{,}403.38\text{hs} / 0.70}{37{,}292\text{Btu/m3 (Nat. Gas LHV)}} * \text{USD } 0.297951\text{m3} = \text{USD } 4{,}130.16$$

Copel Power Plant Displaced Natural Gas Cost Chart:

Fuel Cell Avg. Gas Rate	Fuel Cell Avg. Gas Rate	Displaced Natural Gas	Fuel Cell Nat. Gas Cost
R$ 0.78430 **m3**	USD 0.297951 **m3**	15,058.04 **m3 (LHV)**	USD 4,487.09
R$ 0.78430 **m3**	USD 0.297951 **m3**	13,860.24 **m3 (HHV)**	USD 4,130.16
R$ 0.02285 **Kbtu/h (LHV)**	USD 0.008681 **Kbtu/h (LHV)**	516,879.90 **Kbtu/h (LHV)**	USD 4,487.09
R$ 0.02103 **Kbtu/h (HHV)**	USD 0.007991 **Kbtu/h (HHV)**	516,879.90 **Kbtu/h (HHV)**	USD 4,130.16
R$ 0.07796 **kWh (LHV)**	USD 0.029621 **kWh (LHV)**	151,482.56 **kWh (LHV)**	USD 4,487.09
R$ 0.07176 **kWh (HHV)**	USD 0.027265 **kWh (HHV)**	151,482.56 **kWh (HHV)**	USD 4,130.16

5-Cost of Displaced Electrical Energy due to fuel cell generation:

In Brazil, the National Electrical Energy Agency (ANEEL) regulates and determines the electrical energy rates. For this analyzed period ANEEL had enforced two regulations that determined the electrical energy rate. Following are the listed rate charts used.

Conventional Rate	ANEEL 226 July 2001 to June 2002		ANEEL 226 July 2001 to June 2002	
	Demand R$/kW	Consume R$/kWh	Demand USD/kW	Consume USD/kWh
A4 (13,8V Medium Volt.)	R$ 6.960	R$ 0.10195	USD 2.644	USD 0.03873
B1 (Residential Low Volt)		R$ 0.19781		USD 0.07516
B3 (Comm. & Ind. Low Volt.)		R$ 0.18500		USD 0.07029

Conventional Rate	ANEEL 336 July 2002 to Date		ANEEL 336 July 2002 to Date	
	Demand R$/kW	Consume R$/kWh	Demand USD/kW	Consume USD/kWh
A4 (13,8V Medium Volt.)	R$ 7.720	R$ 0.11312	USD 2.933	USD 0.04298
B1 (Residential Low Volt)		R$ 0.21949		USD 0.08339
B3 (Comm. & Ind. Low Volt.)		R$ 0.20527		USD 0.07799

Copel power plant generated 1,156,313kWh during period, 975,495kWh under the first rate period (ANEEL regulation 226) and 180,818kWh during second one (ANEEL regulation 336). The applicable rate for Copel Data Center is the A4 (13.8V), so the resulting electrical energy savings were:

Elec. Saving = (kW Demand * Months * Demand Rate USD/kW) + (kWh Generated * Consume Rate USD/kWh)

Displaced kWh Rate = Total Electrical Energy Cost / kWh Generated

Rate	kWh Generated	Months	Demand kW	Demand Rate USD / kW	Consume Rate USD/kWh	Total Saving USD	Displaced kWh Rate USD
A4 (ANEEL 226)	975,495.00	11	200	2.644	0.03873	43,597.72	0.04469
A4 (ANEEL 336)	180,818.00	2	200	2.933	0.04298	8,944.76	0.04947
Total	**1,156,313.00**	**13**	**200**			**52,542.48**	**0.04544**

6-Results:

During this period the power plant cost vs. savings did not generate any net savings because of the utilization of natural gas to generate electrical and thermal energy. In fact, the result shows loses that reached USD 133,880.00 (gas HHV). At the same time the resulting power plant electrical energy cost was far from being competitive with the electrical rates available on the State of Parana. The results are described on the next chart.

Considering the application low demand, an analysis was also prepared estimating costs and savings under different demand cases to identify those where the power plant application into the Brazilian power market would generate a positive result. As shown on the next second chart, considering displaced electrical energy at 13.8V rate (A4) the power plant does not generate any savings. Neither when considering the potential benefit of ANEEL regulation 21/2000 that states requirements for cogeneration devices, allowing benefits that reaches to a 50% discount on natural gas cost. Besides at a maximum demand and getting the benefits of ANEEL 21/2000, the power plant electric energy cost, can be competitive with Residential Low Volt Rate (B1) and Commercial & Industrial Low Volt Rate (B3), but not with 13.8V rate (A4).

COST Vs. SAVINGS ANALYSIS

Based on system effective demand for the period

Case	Elec. Cap. Factor	Thermal Util.	Displaced kWh	Displaced Gas kBtu	Capital Amortization USD	First Year Maintenance USD	Nat. Gas Cost USD	Nat. Gas Savings USD	Electrical Savings A4 USD	Net Savings USD
Copel Fuel Cell Cost / Savings Analysis for the Period, based on effective demand										
Nat. Gas LHV	66.39%	5.74%	1,156,313.00	516,879.90	93,987.29	23,581.90	82,749.32	4,487.09	52,542.48	-143,288.95
Nat. Gas HHV	66.39%	5.74%	1,156,313.00	516,879.90	93,987.29	23,581.90	82,749.32	4,130.16	52,542.48	-143,645.88

POWER PLANT ELECTRICAL ENERGY RATE vs. UTILITY GRID ELECTRICAL ENERGY RATES

Based on system effective demand for the period

Case	Elec. Cap. Factor	Thermal Util.	Displaced kWh	Displaced Gas kBtu	Capital Amortization USD	First Year Maintenance USD	Nat. Gas Cost USD	Nat. Gas Savings USD	kWh Generated Cost USD	A4 (13,8V Medium Volt.)	B1 (Residential Low Volt)	B3 (Comm. & Ind. Low Volt.)
Copel Fuel Cell kWh Generated Cost for the Period, based on effective demand, compared with utility grid available rate cost for the same period.												
Nat. Gas LHV	66.39%	5.74%	1,156,313.00	516,879.90	93,987.29	23,581.90	82,749.32	4,487.09	0.16936	0.04544	0.07645	0.07149
Nat. Gas HHV	66.39%	5.74%	1,156,313.00	516,879.90	93,987.29	23,581.90	82,749.32	4,130.16	0.16967	0.04544	0.07645	0.07149

COST Vs. SAVINGS ANALYSIS

Estimations according to different demand percentages.

Case	Elec. Cap. Factor	Thermal Util.	Displaced kWh	Displaced Gas kBtu	Capital Amortization USD	First Year Maintenance USD	Nat. Gas Cost USD	Nat. Gas Savings USD	Electrical Savings A4 USD	Net Savings USD
Copel Fuel Cell Cost / Savings Analysis considering a typical Demand										
Nat. Gas LHV	90.00%	40.00%	1,512,608.40	3,601,448.57	93,987.29	23,581.90	113,374.94	31,264.55	66,670.10	-133,009.49
Nat. Gas HHV	90.00%	40.00%	1,512,608.40	3,601,448.57	93,987.29	23,581.90	113,374.94	28,777.60	66,670.10	-135,496.44
Copel Fuel Cell Cost / Savings Analysis considering a 100% Demand										
Nat. Gas LHV	100.00%	100.00%	1,680,676.00	9,003,621.43	93,987.29	23,581.90	123,653.63	74,008.65	73,301.23	-93,912.95
Nat. Gas HHV	100.00%	100.00%	1,680,676.00	9,003,621.43	93,987.29	23,581.90	123,653.63	68,784.81	73,301.23	-99,136.79
Copel Fuel Cell Cost / Savings Analysis considering a 100% Demand and getting a 50% Benefit on Natural Gas cost as a result of applying to ANEEL 21/2000										
Nat. Gas LHV	100.00%	100.00%	1,680,676.00	9,003,621.43	93,987.29	23,581.90	61,826.82	74,008.65	73,301.23	-32,086.13
Nat. Gas HHV	100.00%	100.00%	1,680,676.00	9,003,621.43	93,987.29	23,581.90	61,826.82	68,784.81	73,301.23	-37,309.97

POWER PLANT ELECTRICAL ENERGY RATE vs. UTILITY GRID ELECTRICAL ENERGY RATES

Estimations according to different demand percentages.

Case	Elec. Cap. Factor	Thermal Util.	Displaced kWh	Displaced Gas kBtu	Capital Amortization USD	First Year Maintenance USD	Nat. Gas Cost USD	Nat. Gas Savings USD	kWh Generated Cost USD	A4 (13,8V Medium Volt.)	B1 (Residential Low Volt)	B3 (Comm. & Ind. Low Volt.)
Copel Fuel Cell kWh Generated Cost, considering a typical Demand, compared with available utility grid rate costs.												
Nat. Gas LHV	90.00%	40.00%	1,512,608.40	3,601,448.57	93,987.29	23,581.90	113,374.94	31,264.55	0.13201	0.04408	0.07656	0.07160
Nat. Gas HHV	90.00%	40.00%	1,512,608.40	3,601,448.57	93,987.29	23,581.90	113,374.94	28,777.60	0.13365	0.04408	0.07656	0.07160
Copel Fuel Cell kWh Generated Cost, considering a 100% Demand, compared with available utility grid rate costs.												
Nat. Gas LHV	100.00%	100.00%	1,680,676.00	9,003,621.43	93,987.29	23,581.90	123,653.63	74,008.65	0.09949	0.04408	0.07656	0.07160
Nat. Gas HHV	100.00%	100.00%	1,680,676.00	9,003,621.43	93,987.29	23,581.90	123,653.63	68,784.81	0.10260	0.04408	0.07656	0.07160
Copel Fuel Cell kWh Generated Cost, considering a 100% Demand and getting a 50% Benefit on Natural Gas cost as a result of applying to ANEEL 21/2000, compared with utility grid available rate costs.												
Nat. Gas LHV	100.00%	100.00%	1,680,676.00	9,003,621.43	93,987.29	23,581.90	61,826.82	74,008.65	0.06271	0.04408	0.07656	0.07160
Nat. Gas HHV	100.00%	100.00%	1,680,676.00	9,003,621.43	93,987.29	23,581.90	61,826.82	68,784.81	0.06581	0.04408	0.07656	0.07160

The combination of many factors affected the economical results. These factors can be summarized under the following categories:

Related to the Application:

- Effective installation cost was 93% more expensive than forecasted as a consequence of the natural gas piping construction.
- 50% of the shutdowns were caused by factors not related to power plant performance, affecting the forecasted maintenance costs.
- Low Electrical Capacity Utilization (67%)
- Limited availability of Thermal Loads (6%)

Related to the Brazilian Energy Market:

- The cost difference between natural gas and electrical energy rate, demands a high efficiency for the electrical generation from the gas utilization in order to turn it equal to conventional electrical market rates and without considering amortization or maintenance costs factors. As demonstrated project displaced electricity rate, was USD 0.04544 kWh; the natural gas rate was USD 0.027265kWh just in order to equalize both rates the power plant should reach to 60% efficiency.
  The small difference does not provide the necessary savings to support maintenance cost and amortization rate, being the result that the electrical generation from the power plant is more expensive than conventional electrical rates.

Related to the Power Plant

- The high cost of acquisition creates a high amortization rate per year.

Conclusions:

According to the evaluation of the results we conclude that the power plant has demonstrated to be a reliable system that complies with premium power supply requirements.
In terms of efficiency, the power plant has demonstrated to perform better than other technologies when referring to electric energy generation. The power plant considerable thermal output represents an additional advantage and its utilization on applications with available thermal loads not only improves the system efficiency but also contributes to the economical viability of the project results.
It was also demonstrated that the use of fuel cell technology greatly contributes to the improvement of the local environment by not releasing harmful emissions.
At this time the commercialization efforts to promote fuel cell technology presents a barrier due to the expensive cost of the equipment compared with traditional sources of power generation, becoming competitive when critical factors are considered as a measure of success.
The achievement of this project has without a doubt contributed to exposing fuel cell technology to a new continent, providing a source of regional evaluation, technical education and expertise and a path to commercial opportunities that will be applicable on future projects.
We can conclude that fuel cell technology provides a reliable option for the maturing concept of distributed generation as an important alternative for environmental clean power generation.

Statistics:

Period Summary Statistics: August 23rd, 2001 through August 31st, 2002.

Hours of Operation:	8403 Hours	Electric Efficiency:	38.6%
Total Electric Output:	1,156.31 MWhrs	Thermal Efficiency:	3.5%
Average Fuel Cell Output:	132.8 kW	Total Efficiency:	42.1%
Total Heat Recovered:	361.8 MMBtu	Electric Capacity Factor:	66.39%
Heat Recovery Rate:	43.056 kBtu/Hr	Availability:	93.7%
Input Fuel:	10,525,927 Cubic Feet		

Month	Operating Hours	Calendar Time	KWHRS	Average AC Output kW	Nat. Gas Consume Cubic Feet	Heat Recovered KBTUHRS	Availability %	Avg. El. Eff. Nat. Gas LHV	Avg. Therm. Eff. Nat. Gas LHV
Aug-01	192	192	37195.30	184.5	331988	8257.4	100.0%	39.3%	2.6%
CTD	192	192	37195.30	184.5	331988	8257.4	100.0%	39.3%	2.6%
Sep-01	714	714	129239.80	178.8	1206821	30735.7	100.0%	37.6%	2.6%
CTD	931	931	171601.60	181.6	1584969	40102.5	100.0%	38.0%	2.6%
Oct-01	718	739	117599.90	155.6	1055128	30923.4	97.2%	39.1%	3.0%
CTD	1655	1675	290198.90	172.9	2649070	71241.2	98.8%	38.5%	2.8%
Nov-01	714	714	89239.10	125.0	790805	30727.4	100.0%	39.6%	4.0%
CTD	2374	2395	380209.20	160.9	3446634	102234.9	99.1%	38.7%	3.1%
Dec-01	628	729	78285.50	106.0	696037	27056.3	86.2%	39.5%	4.0%
CTD	3009	3131	459307.60	150.0	4149823	129571.9	96.1%	38.9%	3.2%
Jan-02	485	723	76691.00	102.8	732406	20863.6	67.0%	36.8%	2.9%
CTD	3494	3878	535998.60	142.1	4882229	150435.4	90.1%	38.5%	3.2%
Feb-02	671	671	83815.00	123.3	763227	28889.8	100.0%	38.6%	3.9%
CTD	4171	4556	620758.40	139.4	5654162	179600.8	91.6%	38.5%	3.3%
Mar-02	743	743	103131.30	138.6	943890	32004.9	100.0%	38.4%	3.5%
CTD	4915	5299	723960.90	139.3	6598499	211625.9	92.8%	38.5%	3.3%
Apr-02	641	715	82362.60	125.7	753814	27597.3	89.7%	38.4%	3.8%
CTD	5561	6019	806874.90	137.8	7357319	239417.0	92.4%	38.5%	3.3%
May-02	720	720	86443.30	121.0	784299	30993.7	100.0%	38.7%	4.1%
CTD	6304	6762	896061.50	136.1	8166458	271435.5	93.2%	38.5%	3.4%
Jun-02	660	714	78877.60	115.5	712423	28435.7	92.4%	38.9%	4.1%
CTD	6970	7482	975495.00	134.2	8883835	300086.5	93.2%	38.5%	3.5%
Jul-02	739	739	90172.00	123.0	812900	31812.0	100.0%	38.9%	4.0%
CTD	7714	8226	1066233.00	133.3	9701787	332113.7	93.8%	38.6%	3.5%
Aug-02	685	739	89400.00	126.6	817980	29486.9	92.7%	38.4%	3.7%
CTD	**8403**	**8970**	**1156313.00**	**132.8**	**10525927**	**361815.9**	**93.7%**	**38.6%**	**3.5%**

Information Source

i. Cogeneration Case Studies of the DoD Fuel Cell Demonstration Program
(Presented at the IQPC F-CELL Stationary Conference London, UK - February 29,2000)

ii. Experience with the DoD Fleet of 30 Fuel Cell Generators
(Presented at the 2001 International Gas Research Conference –IGRC 2001- November 5-8, 2001)

iii. Gas and Electricity Rates on South America (Protecnia IAPG Magazine, Nº4 August, 2002)

iv. UTC Fuel Cell (www.utcfuelcells.com)

v. DoD Fuel Cell ERDC-CERL (www.dodfuelcell.com)

vi. Companhia Paranaense de Energia – COPEL - (www.copel.com)

vii. Companhia Paranaense de Gas – COMPAGAS - (www.compagas.com)

viii. IAPG Argentine Institute of Petroleum and Gas (www.iapg.org.ar)

Photo Gallery

"Fuel Cell Arrival"

"Fuel Cell Positioning"

"Copel Site Preparation"

"Fuel Cell on Site"

"Fuel Cell on Site after Reconditioning for Promotional Purposes"

"Fuel Cell Operating"

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